White Paper
Intel® Data Center
Efficiency Technology

Intel® Eco-Rack

Achieving 16-18% total power savings with a server rack designed for excellence in power efficiency

Executive Summary

Achieving global goals for environmental protection, conservation, and sustainability will require new technological advancements. One area in which Intel and others in the computing industry are focusing efforts is improving energy efficiency in data centers. A relatively recent phenomenon of the last few decades, data centers today consume a notable percentage of the world's energy—about 1.5 percent of U.S. total electricity consumption in 2006, according to the U.S. Environmental Protection Agency (EPA).

A recent example of Intel's efforts is the Intel® Eco-Rack Proof of Concept demonstration, a real-world test of the power savings possible in rack-mounted servers using today's advanced technologies. Developed at Intel facilities in both Hillsboro, Oregon and DuPont, Washington, and inspired by discussions with the EPA and Lawrence Berkeley National Labs (LBNL), this demonstration showcases several industry advancements in energy-efficient technology for the data center.

In September 2007, an Eco-Rack using 30 rack-mounted servers demonstrated how server-level configuration changes—such as moving to servers equipped with new energy-efficient processors, converting to DC power delivery to servers, activating Enhanced Intel SpeedStep® Technology in the BIOS, and using more efficient 2 GB memory modules—can deliver significant savings at the rack-level for today's data centers. Incorporating these changes resulted in an overall savings of up to 18-percent measured total power savings when running compute-intensive enterprise applications such as SPECjbb, a warehousing application simulating many transactions at the same time.

This innovative demonstration serves as an education tool to illustrate:

- The real-world possibilities inherent in leading-edge technologies
- The financial benefits energy-efficient technologies offer data centers
- The productivity gains that more energy-efficient data centers can deliver to businesses, governments, and other organizations

The future looks bright for more power-saving developments such as the Eco-Rack. Intel and the industry are continuing to address the challenge of powering tomorrow's data centers and reducing their environmental footprint through a broad set of innovations that enable more work to be done with less power.

Introduction

As economies around the world depend increasingly on digital information management, data centers housing the electronic equipment used for data processing, data storage, and communications networking have become essential to business, transportation, communications, government, and academic institutions. Driving the demand for more and larger data centers are their importance in:

- Electronic transactions in financial services, such as on-line banking and electronic trading
- Internet communications and entertainment
- Electronic record keeping for healthcare
- Global commerce and services
- Satellite navigation and electronic shipment tracking in transportation
- Emergency, health and safety services
- Information security and national security
- High performance scientific computing
- Digital provision of government services, such as electronic filing of taxes and online postal tracking

The sheer number of people adopting and using Internet and related online services and applications is also driving data center growth. According to JupiterResearch's "*Worldwide Online Population Forecast, 2006 to 2011*," 1.1 billion people currently enjoy regular access to the Internet. This report goes on to predict that a compound annual growth rate of 6.6 percent will increase the number of people with regular online access to approximately 1.5 billion people (or 22 percent of the Earth's population) in 2011.

Powering the data centers serving this growing number of online users is another matter. Data centers are a fast-growing phenomenon in the world of power consumption. According to the U.S. EPA, the nation's data centers and servers consumed about 1.5 percent of the U.S. total electricity consumption in 2006.[1] To put this in perspective, the EPA notes that this is more than the electricity consumed by the nation's color televisions and is "similar to the amount of electricity consumed by approximately 5.8 million average U.S. households (or around five percent of the total U.S. housing stock)."

This same EPA report also suggests the problem is going to continue to grow, forcing data centers to compete for increasingly limited power resources with every other electrical user, from heavy industry to home users. The EPA predicts that "under current efficiency trends, national energy consumption by servers and data centers could nearly double again in another five years (i.e., by 2011) to more than 100 billion kWh, representing a USD 7.4 billion annual electricity cost" and the addition of 10 power plants to the nation's power grid.[2]

But competition for electricity is only one challenge data centers face. The cost of power also is troubling to many data center operators. According to Gartner, as power requirements continue to grow, energy costs will emerge as the second highest operating cost (after personnel) in 70% of worldwide data center facilities by 2009.[3] The average annual power costs for a 100,000 square-foot data center is nearly USD 6 million.[4] Some organizations are already cutting back on expansion because adding more servers would require a complete overhaul of the entire power and cooling infrastructure of their data center.

Equally alarming, many data centers have reached the limits of the power capacity for which they were designed. Gartner says 50 percent of data centers will have insufficient power and cooling capacity by 2008.[5]

Microprocessors Are an Important Part of the Solution

What's surprising is that these problems are appearing despite some of the greatest energy efficiency gains per unit of processing power the world has ever seen. In March 2007, for instance, Intel introduced two energy-efficient 50-watt server processors, the Quad-Core Intel® Xeon® processor L5320 and L5310. These products deliver a 35- to nearly 60-percent decrease in power from Intel's existing 80- and 120-watt quad-core server products, yet provide similar performance. Setting a new standard in energy efficiency, these processors represent a nearly ten-fold improvement in power consumption per core in just 1½ years.[6] (Note: The Eco-Rack uses an even newer processor.)

Rob Enderle, principal analyst at the Enderle Group, in praising the Quad-Core Intel Xeon processors L5320 and L5310, noted that such technology can prevent or postpone the need to increase cooling and power requirements for existing data centers, avoiding or delaying the spending of billions of dollars across the segment for site upgrades and relocations.[7]

Unfortunately such processor efficiency gains aren't being capitalized on yet. Many data centers are still running legacy equipment. A former director of Intel's IT operations admits that's true even at Intel, but that the company is moving faster now in taking advantage of its processor advances. He was quoted as saying that "a six-year-old server takes up valuable resources that could be better used, so we [Intel] have accelerated our refresh rate. Refreshing one data center gave us [Intel] three times the performance ..."[8]

Saving Energy in Data Centers Requires More than Energy-Efficient Processors

Choosing servers with energy-efficient processors is just part of the solution. A data center with all its systems for power conversion, distribution, backup storage, and cooling has many other options than just its computing power (processors) for saving energy. So, while much has been done to improve processor performance and efficiency, Intel and other industry leaders believe it's time to take a more holistic approach to planning, designing and laying out the data center to optimize power and cooling capacity. This includes finding ways to optimize all the variables, including building type, building systems, rack configuration, power conversion and distribution, monitoring and managing workloads, airflow dynamics, and many other energy-consumption factors.

Intel and the industry are addressing these variables through a broad set of innovations designed to enable data centers to do more work with less power. One of Intel's current efforts is the Eco-Rack Proof of Concept, a demonstration of what can be achieved today using best-in-class components and practices.

This paper will describe the Eco-Rack's objectives, setup, and results.

The importance of rack-mounted servers

To understand why Intel chose to focus on server racks, it's important to understand their advantages in the modern data center. Today's high-density rack-mounted servers reduce space, cooling, networking, cabling, and management costs—as well as total power consumption—compared to low-density configurations having far few servers per rack. However, some data centers fear rack-mounted servers will drive up power density to levels exceeding the limits of their facilities.

While the power density of a fully-populated rack of 1U rack-mounted servers may be too high for most data centers,[9] many advantages of these racks—such as the lower power consumption per server—can be gained at lower densities. In fact, the primary total cost of ownership (TCO) benefit related to their use comes from their reduced power consumption, not their reduced space consumption. What's more, through more modern cooling designs that cool just the racks, not the entire facility, even more savings are possible. Consequently, by installing rack-mounted servers at various densities, data centers could realize greater TCO benefits.[10]

Objectives for the Eco-Rack Proof of Concept

The Intel Eco-Rack Proof of Concept is a real-world example of the power savings possible by reducing the environmental footprint of data centers through the use of rack-mounted servers employing today's most advanced technologies. Developed at Intel facilities in Hillsboro, Oregon and DuPont, Washington, the demonstration showcases industry advancements in the delivery of energy-efficient technology for the data center. It was designed to serve as an education tool to illustrate the real-world possibilities inherent in leading-edge technologies, the financial benefits their energy savings provide data centers, and the productivity gains that more energy-efficient data centers can deliver to businesses, governments, and other organizations.

With the Eco-Rack Proof of Concept, Intel intended to show how through relatively modest modifications to today's best-in-class server rack components, the power consumption of rack-mounted servers could be further reduced and make better use of the power they consume.

It should be noted that reducing power consumed in a data center has considerable ramifications in reducing heat and thus cooling costs. Every watt of power directly consumed by silicon in a typical data center requires another one watt for power conversion (based on standard 75-percent efficient power supplies and 88-percent uninterruptible power supplies) and another watt for cooling the two watts of load (one watt, silicon; one watt, power conversion).

Test setups

To ensure a fair comparison, Intel set up two test racks—the Eco-Rack and a typical modern AC configuration—each holding 30 1U rack-mounted servers. Each server featured two Intel® Xeon® Processors X5355 (2.66 GHz). All servers were running Fedora Core 5 64-bit with Kernel 2.6.15-1.2054_FC5 with IPMI enabled. The power factor for the uninterruptible power supplies (UPS) on the standard rack setup—referred to as the Modern Alternating Current (AC) Configuration in this paper—was 0.99. This 0.99 power factor was equivalent to the UPS performance of the direct current (DC)-based Eco-Rack setup, which, because it's a DC-based system, required no complex power phasing.

The goal was to compare a typical modern configuration with an Eco-Rack design providing equal performance, but requiring less power.

Below we further describe each configuration.

Test Setup

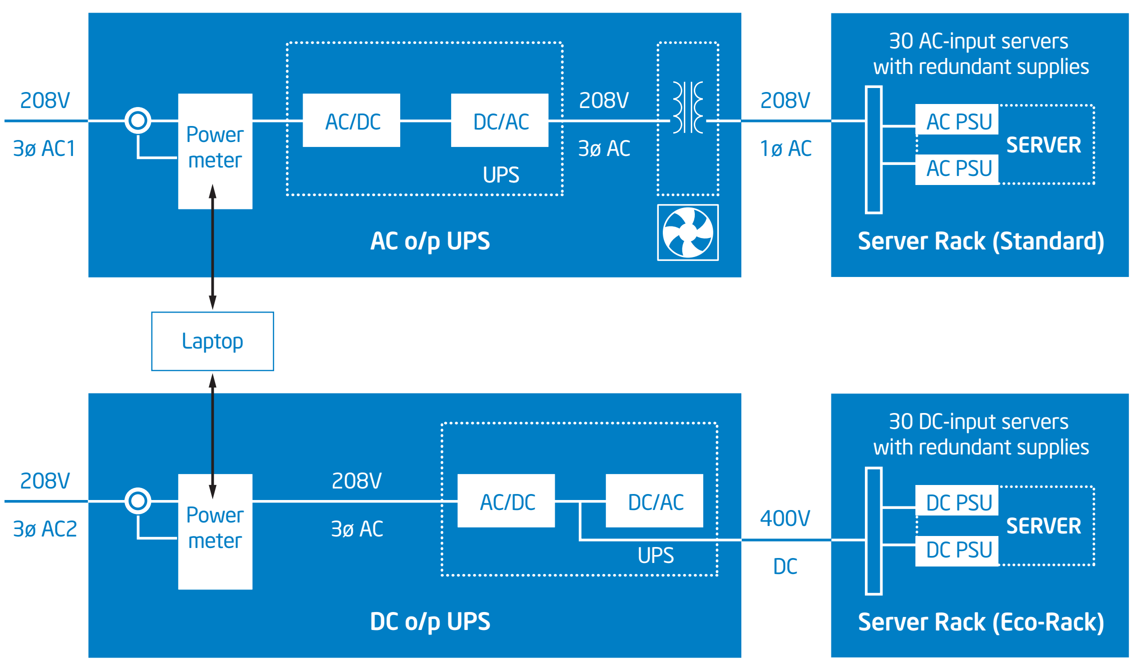


Figure 1. Standard Rack setup vs. Eco-Rack setup, note less conversion stages in Eco-Rack.

Modern AC Configuration

This setup featured 30 1U rack-mounted servers equipped with Quad-Core Intel® Xeon® Processors X5355 (2.66 GHz, Stepping 7) and 8 GB of memory supplied by eight 1GB Fully Buffered (FB)-DIMMs. Supported by the Intel® 5000 chipset family and FB-DIMM technology, Quad-Core Intel Xeon processor 5300 series-based platforms deliver breakthrough performance with better power efficiency, delivering up to 1.5 times the performance compared to leading Dual-Core Intel® Xeon® processor 5100 series in the same power envelope and up to 2.4 times the performance compared to the best published results of AMD Opteron* Model 2222.[11]

To provide the best possible setup for comparison with the Eco-Rack, we configured this modern rack with best-in-class components that are commercially available today. This includes using 90-percent efficient power supply units (PSUs) for both the main and redundant PSUs for each system.

To provide the most accurate reading on power draw, we measured current coming directly from the wall rather than after it passed through a UPS.

In a typical data center, 480 volts is stepped down through a power distribution unit (PDU) to 208 volts AC to feed each server in the rack. To simulate this using 208 volts AC, we step across 208 AC through a PDU after it passes through the UPS. The power supply units (PSUs) and, later the voltage regulators, in each server then progressively convert and step down the current to the 12 volts and less DC required by the various server components. While the typical power conversion efficiency for the conventional architecture is just below 50 percent, a system using best-in-class components like this one can achieve up to 71 percent efficiency.

Eco-Rack Configuration. This setup featured 30 1U rack-mounted servers equipped with Quad-Core Intel Xeon Processors X5355 (2.66 GHz, Stepping 11) and 8 GB of memory supplied by four 2 GB Fully Buffered (FB)-DIMMs.

To use DC power, we deactivated the DC-back-to-AC power conversion in the UPS and sent the 400V DC directly to a DC power strip for the servers. Servers were equipped with DC PSUs to progressively step down the current to the 12 volts and less DC required by the various server components. Again, to provide the most accurate reading on power draw, we measured current coming directly from the wall rather than after it passed through a UPS.

Server Detail

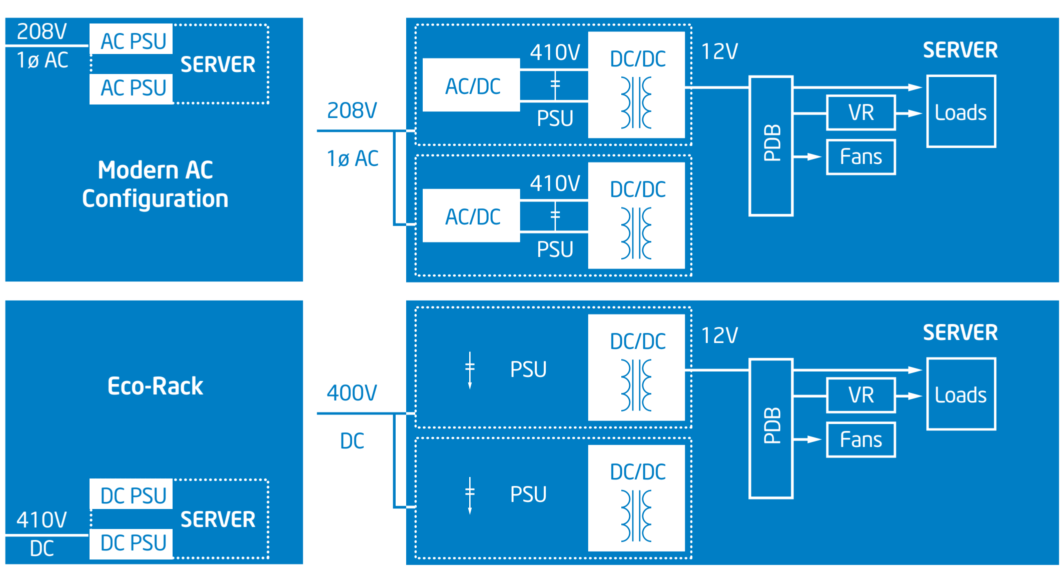


Figure 2. Power distribution details within each server, note less conversion stages in Eco-Rack.

Primary configuration differences

Power Conversion

For the Eco-Rack setup, we eliminated the initial power conversion step by using 400 volts DC power directly. This improves energy efficiency by reducing the power losses due to: 1) power conversion, and 2) cooling the excess heat that this conversion generates.

Processor

To demonstrate upcoming processor efficiencies, we equipped the Eco-Rack with its latest Quad-Core Intel Xeon Processors X5355 (2.66 GHz, Stepping 11). This processor provides better idle state performance.

BIOS Settings

In the BIOS, Intel did something many implementations would profit from doing. We activated the setting for Enhanced Intel SpeedStep Technology. This feature enables Intel® Server Boards to dynamically ramp (up and down) processor speed and voltages to minimize power consumption and reduce operating costs in accordance with load. Many server implementations don't activate this technology thinking that by not using it, they will achieve maximum responsiveness. In truth, servers in many typical IT data centers operate at the wide range of loads (as compared to the more consistently high utilization experienced by high-performance computing data centers). Activating Enhanced Intel SpeedStep Technology can reduce power consumption and cooling costs of servers by as much as 25 percent.

System Firmware

Many server manufacturers are overly conservative in their system firmware. This is the set of instructions programmed on a server that holds information on the type and number of processors, fans, memory, power supplies, and other components. Often, rather than being set correctly, system firmware runs in a default mode that plays it safe by maximizing settings such as fan speed, rather than providing speeds more appropriate to the type and number of processors and various other components. By running the fans at top speed, default modes use more power than necessary. Up to 200 to 300 watts can frequently be saved in a rack of 30 servers by updating the system firmware with the correct settings.

Memory Configuration

Another modification we made for the Eco-Rack involved memory configuration. Instead of the eight 1 GB FB-DIMMs used by the Modern AC Configuration, the Eco-Rack uses four 2 GB FB-DIMMs. Using fewer memory modules (four versus eight) reduces active power consumption, produces less heat, and requires less energy to be spent in cooling. It is important to note that for optimum performance, FB-DIMM memory modules should be equally divided between the memory channels (e.g., one memory module for each of four memory channels).

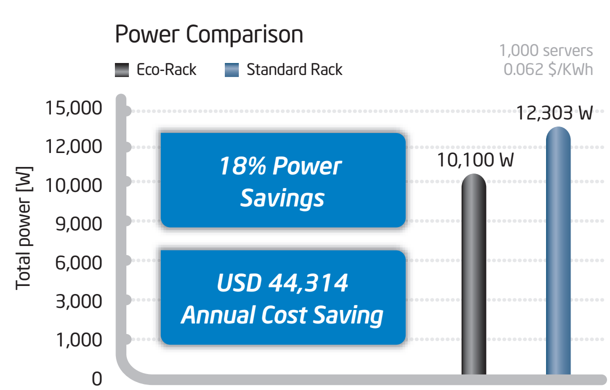
The tests

Tests were done under the guidance of the Lawrence Berkeley National Laboratory in California. Both test configurations ran JILL5, a version of the industry-standard SPECjbb benchmark that tests Java Virtual Machine performance by running a Java-based order fulfillment warehouse application. SPECjbb is generally regarded by the industry as being a realistic JVM performance benchmark with a real-world typical instruction mix. JILL5/SpecJbb does not measure I/O performance (e.g., disk, network) since all its transaction requests are synthesized internally. It's strictly a CPU benchmark.

One of the configuration parameters is the number of warehouses to run in parallel. For power-measurement purposes, we did separate runs at two, four, and eight warehouses to approximate 200, 400, and 800 percent of normalized single-CPU utilization.

Since JILL5/SPECjbb is intended to be a benchmark, it is normally run for a fixed amount of wall clock time, after which it reports a result in billions of operations per second (bops). Since we're using it to simulate a continuous system load instead of as a benchmark, we set its run-time to 9...999 minutes instead of the normal benchmark runtime. We never wait for it to finish.

Note that as the number of warehouses-in-parallel approaches the number of logical processors, the CPU utilization drops a bit below the theoretically attainable amount of 100 percent of X number of warehouses. This is due to the warehouse threads contending with one another for some single resource such as a lock on the results-counter, overall memory contention, other CPU resources, etc.



Test results

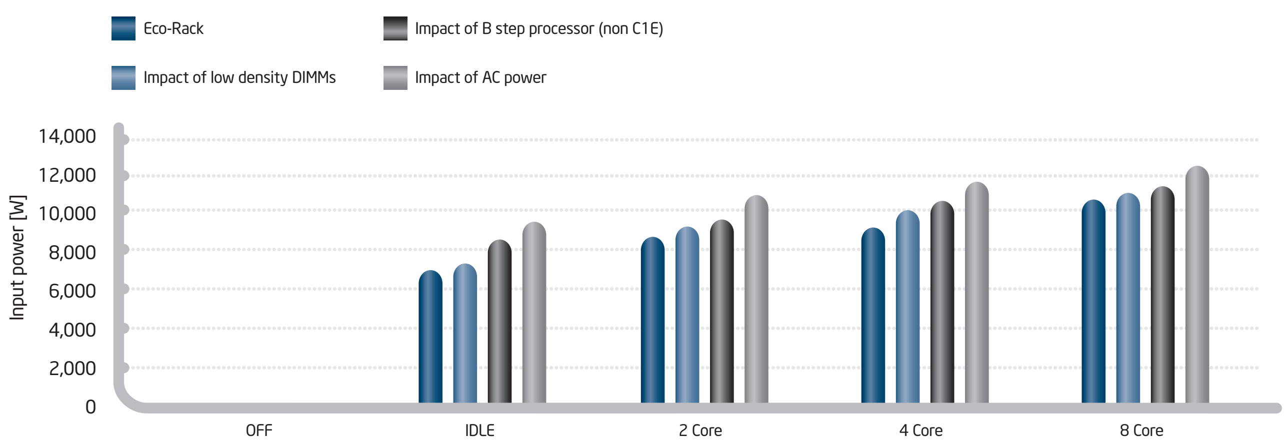
Running JILL5/SPECjbb, the Eco-Rack demonstrated from 16 to 18 percent measured total power savings, depending on workload or configuration.

Projecting the highest power savings (18 percent) to a data center with 1,000 servers and a power cost of USD 0.062 per kilowatt hour, the modest changes represented by the Eco-Rack configuration could annually save a company or organization USD 44,314.

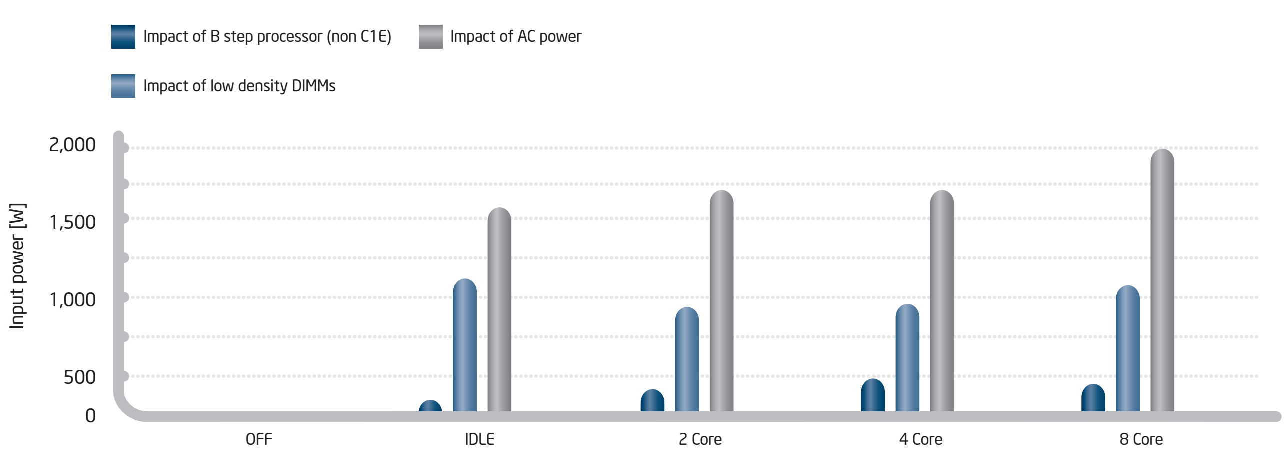
In a power-constrained environment, these same power savings could also be used to make better use of available power and add more compute cycles. (See hypothetical example below.)

To determine which components of the Modern AC Configuration contribute greatest to energy costs, we disabled various components of the Eco-Rack and added back the Modern AC Configuration components one at a time. The results are shown in the following charts.

Input Power Breakdown



Technology Impact



A hypothetical example of how data center power constraints affect operations

To see the advantages of something like the Eco-Rack and other data center energy efficiency enhancements, it's helpful to look at a hypothetical example of how the power constraints of a data center might actually hurt a company's bottom line.

Consider a financial firm that's faced with a data center that has outgrown its power resources. Like many financial companies, this firm has to borrow a certain amount of money at the end of every day to hedge its next day's loans and other money it needs to have available. If the firm doesn't have enough power in their data center to run the compute cycles it needs to accurately compute how much it needs to borrow, the firm has to increase this hedge, borrowing more than necessary to be "safe." Many financial companies do this, borrowing and paying for more money than they need to make up for their inability to accurately and quickly calculate what they need for the next day. This directly affects a firm's profits. By updating their data centers with innovations such as those demonstrated by the Eco-Rack (more energy-efficient processors, power supplies, BIOS setting, and memory configurations), financial firms could make better use of their available power and potentially gain the compute cycles they need to much more accurately compute their daily hedge. For many, the interest saved on borrowed hedge money would far outweigh the cost of the power to run these compute cycles on the more efficient servers.

Conclusions

The Eco-Rack Proof of Concept demonstrates how server-level changes—such as moving to servers equipped with new energy-efficient processors, converting to DC power delivery to servers, activating Enhanced Intel SpeedStep Technology in the BIOS, and using more efficient 2 GB memory modules—can deliver significant savings at the rack-level for today's data centers. Incorporating these changes resulted in an overall savings of up to 18 percent measured total power savings when running compute-intensive enterprise applications such as SPECjbb, a warehousing application simulating many transactions at the same time.

Many of these "small" changes are things data center managers can do today. Specifying best-in-class, energy-efficient components in everything from server processors to PSUs and memory modules can go a long way to saving energy and reducing TCO. So can utilizing power optimization features and settings. Other changes, such as DC power components, will take more time for the industry to adopt.

The future looks bright. Intel and the industry are continuing to address the challenge of powering tomorrow's data centers and reducing their environmental footprint through a broad set of innovations that enable more work to be done with less power. We summarize many of these below.

Promising power-reduction technologies and strategies for data centers

400V DC Distribution

Having each server in the rack accept 400V DC reduces the number of power conversion stages compared to the Modern AC Configuration. The DC-to-AC conversion in the UPS, the AC-to-AC conversion in the PDU transformer, and the AC-to-DC conversion in the PSU are eliminated. Fewer power conversion steps reduce energy lost to conversions and result in fewer power conversion components to cool. In addition, since fewer components are required for power conversion, system reliability is expected to increase.

Distribution at 400V DC also allows for more efficient connection of renewable energy sources to the building loads since most renewable energy sources (e.g., fuel cells and photovoltaic panels) generate a DC voltage. The use of DC power also eliminates the need for balancing the load across the three phases as required in AC distribution. This saves time and effort and eliminates the need for equipment monitoring the load imbalance.

Overall, the advantages of direct higher voltage DC distribution (400 VDC) as compared to high efficiency AC distribution (480V/208 VAC) include:

- Removes redundant conversion in end-to-end data center power architecture
- Energy-efficiency gain estimated to be five to 10 percent across the full load range
- 10 times higher availability
- Commonly available UPS, battery, and PSU technology (just fewer parts)
- Lower thermal footprint
- No complex power phasing/balancing
- Easy-to-parallel power sources

High Performance, Energy-Efficient Quad-Core Processors Based on Intel® Core™ Microarchitecture

For every watt saved in computation, two additional watts are saved—one watt in power conversion and one watt in cooling (the result of no longer having to cool two watts in computation and power conversion). Consequently, big power savings can be gained from small percentages in processor power savings. In the second half of 2007, Intel will introduce its first family of 45 nm processors. Codenamed Penryn, this family includes new dual- and quad-core Intel Xeon processors. The Penryn family's microarchitecture optimizations will further increase the overall performance and energy efficiency of the already leading Intel Core microarchitecture. Processors based on this microarchitecture will deliver even more instructions, executions per clock cycle, and speed up the performance of a variety of applications.

Processor Voltage Optimization

Intel Core microarchitecture's Intelligent Power Capability throttles down processor performance in response to lower demand. This capability enables excellent energy efficiency in a wide variety of loads. Data centers using the latest Intel processors will profit from this technology.

Optimizing BIOS and System Firmware Settings

Through Enhanced Intel SpeedStep Technology, Intel® Server Boards can dynamically ramp processor speed and voltages to minimize power consumption and reduce operating costs. By turning on Enhanced Intel SpeedStep Technology through the BIOS, data center managers can reduce server power consumption and cooling costs by up to 25% with little effect[13] on performance. Updating system firmware settings to appropriately reflect system components, such as processor number, and type, and fan speeds, can often reduce the speed at which fans run, providing additional power savings.

Greater Than 90 Percent Efficient PSUs

Typical server PSUs (one element in a data center's power conversion chain) are only 50 percent efficient, yet units can be purchased that are 90 percent efficient or more and pay for their additional cost in less than a year. Depending on the number of servers in a data center, 90 percent efficient PSUs can have a significant effect on power savings.

Improved Rack Design

Cooled doors, chimneys, raised floors, and other data center design improvements increase air flow effectiveness and reduce cooling costs. Much information is already available from Intel and other sources on ways to design data centers so cooling is directed at the components putting out the heat and not at the facility at large.[14]

Server Consolidation

In many data centers, more servers are running than necessary for the work being done. A study by Hewlett Packard Lab of six corporate data centers studied 1,000 servers and found that most were using only 10 to 25 percent of their capacity. To combat this trend, a major Intel focus is promoting better server utilization through server consolidation. Consolidation through virtualization reduces the number of physical servers required, thereby helping to minimize floor space, cooling, and capital costs. Many data center operators are responding to the call for consolidation by installing virtual machine software on powerful Intel®-based servers equipped with Intel® Virtualization Technology. This enables a single server to run multiple operating systems and applications.

An important benefit of server consolidation is greater energy efficiency. Having fewer servers do more work reduces both the number of servers drawing power and the number of servers that need cooling.

Intel's upcoming 45 nm Penryn server processors will improve virtualized server performances, encouraging even more server consolidation. Through enhanced Intel Virtualization Technology, these processors will speed up virtual machine transition (entry/exit) times by an average of 25 to 75 percent.

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